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Getting good fit

'Fit' can be seen as two quite different problems. The first occurs when no attempt is made to co-ordinate dimensions; for example, the plan dimensions of a kitchen may bear no relationship whatever to the dimensions of, say, standard kitchen furniture. The second problem becomes apparent when, for example, a bath proves to be just too long for the space between two opposite walls in a bathroom, so that a chase must be cut to accommodate the flange. The first kind of problem is usually seen as one which the designers (of buildings or of kitchen furniture) should have foreseen and solved; the second kind is usually seen as a builder's mistake. This digest shows how these two aspects of fit are really successive parts of a single problem: a problem met in all forms of construction and involving all the participants in the construction process.

Designer, manufacturer and builder

A building designer wants all the parts of the building to fit together well so as to obtain the intended performance: so that the builder can, in practice, build what the designer intended. This can happen only if the designer makes the right decisions about sizes, joints, accuracy and tolerances. The manufacturer wants his components to have a reputation for being free from installation problems and for being usable in a wide variety of building situations, not just those where they are built in as the work proceeds. This can happen only if he makes the right decisions about sizes and the dimensional characteristics of the components. A builder wants to avoid the problems that arise from lack of fit and the consequent delays, disputes and disruption of the work flow. This can happen only if he understands the basis of the designer's decisions and their consequences for him. All want to avoid unnecessary waste in materials and labour and to achieve a neat and satisfactory job on completion.

Will better fit cost more?

Designing so that the parts of building fit together satisfactorily is not inevitably dependent on 'tighter tolerances' (which usually cost more) or on 'bigger joints' (which may not perform well). It does require better descriptions of accuracy than those usually used in the building industry; and it requires a better description of joint dimensions. It requires more care in design but better decisions can then be made about target sizes for components and construction, so that the probability of a misfit occurring is reduced to the minimum; so too is the cost of rejections, rectification, disruption of work and impairment of performance.

Better fit will, therefore, probably cost less.

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Avoiding the problem: 'designing it out'

We are accustomed to think of 'fit' as a problem only because we are accustomed to the lack of a solution for it. Once a technique for solving it is available, 'fit' is no longer a problem and the designer is free to choose whether or not to 'design it out'. If he chooses to design it out, it becomes particularly important to check that a proposed design does indeed remove the need to consider fit. For example, the use of a lap joint rather than a butt joint, Figures 1 and 2.

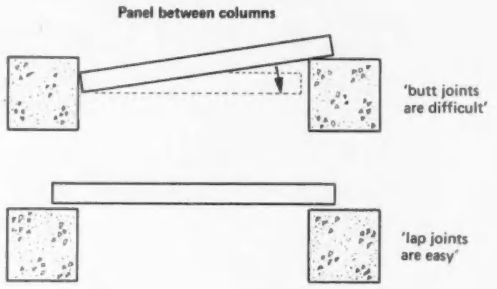


Fig 1 Lap joints may be better . . .

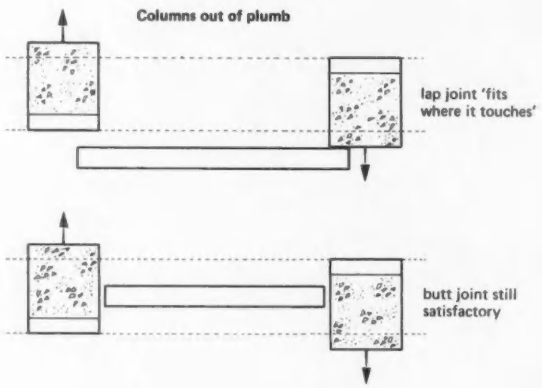
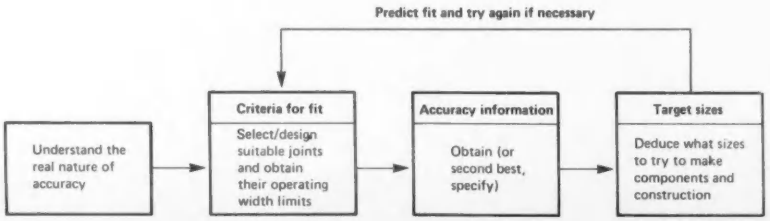


Fig 2 . . . but only if the circumstances are right

Tackling the problem

The idea of a technique for tackling the problem of fit in advance is new to an industry accustomed to thinking that the problem is ultimately one for the builder and to be solved, therefore, on site and as the need arises. But it *can* be tackled in advance and while the need for correction on site may not be completely removed it can at least be reduced to a minimum. Techniques for solving the problem already exist and more data for use with them are becoming available.

Tackling the problem can be generalised like this:


Predict fit and try again if necessary
Understand the real nature of accuracy
Criteria for fit
Select/design suitable joints and obtain their operating width limits
Accuracy information
Obtain (or second best, specify)
Target sizes
Deduce what sizes to try to make components and construction

What is accuracy?

Nothing can be made with absolute precision: every manufacturing or building process has its own characteristic accuracy, which is reflected in the dimensions of the end-products. Unfortunately, this leads to a misconception: that the characteristic accuracy of a type of component or construction can be described by limits, for example '3000 ± 15 mm'. This description is inadequate because it does not reflect the probability that far more achieved sizes will be at, or near to, the target of 3000 mm than will be at 15 mm from it. The products of most processes aimed at achieving a particular target size follow what is called a *normal distribution*, in which sizes near the target are common and those increasingly further from it are increasingly rare (as might be expected from experience).

Applying this to the example, although sizes that are more than ±15 mm from the target size of 3000 mm may be very rare, there is still some probability that they will occur. But more importantly we are much more likely to encounter sizes around 3000 mm than around 2985 mm or 3015 mm.

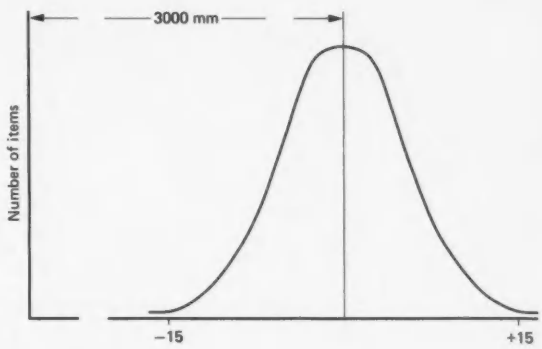


Fig 3 Normal distribution

Suppose that sizes outside the range of 3000 ± 10 mm will not be satisfactory: will not fit. The proportion of items that is likely to need to be rejected or rectified, represented by the shaded areas in Figure 4, can be predicted. If we think the proportion is too high and too costly, it is not necessary to wait until the problem reveals itself during construction: we can make better design decisions before any items are manufactured or constructed.

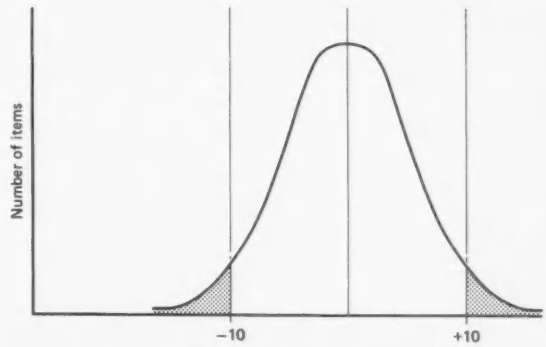


Fig 4 Tolerance imposed on normal distribution

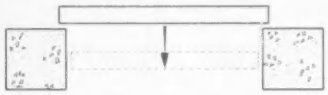


Fig 5 . . . item does not fit . . .

What is the criterion?

Problems of fit make themselves known at joints. In the simplest case, an item does not fit because it is too big to enter the space available: the joints widths are less than zero. Suppose the item had been just small enough to enter the space, the joint widths being, say, 1 mm: for practical purposes no satisfactory joint could be made in such a small clearance. It is not enough that the item can just be entered into the space: to be able to say that it fits satisfactorily in practical terms it might, for example, need to leave clearances for the intended joint of at least 5 mm. Other potentially suitable joints might have different minimum clearance requirements.

Again, in practice, suitable joints have maximum clearance requirements too. For example, in an open drained joint, the baffle may disengage from the groove in joints wider than a certain value dependent on the dimensions of the parts concerned. The limits within which a joint clearance should lie can be seen by considering the design of the joint concerned and the dimensional needs of its parts. But because the inaccuracies in components and construction can be accommodated only at the joints, joint widths also will follow a predictable distribution. This can be compared with the permissible limits (Figure 6).

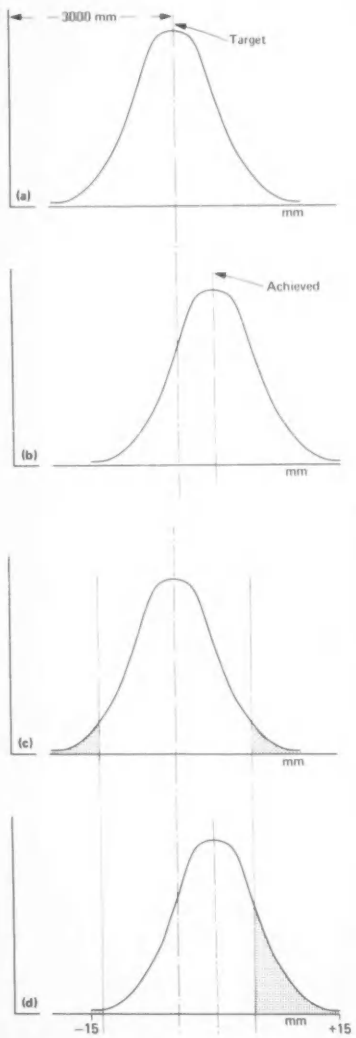


Fig 7 Sometimes . . . sizes are characteristically a little larger or smaller on average than intended

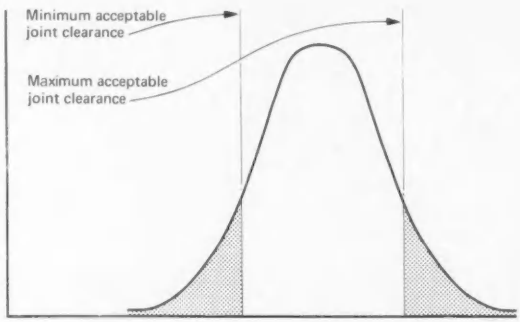


Fig 6 Joint clearances imposed on normal distribution

The proportion of joint clearance limits likely to need to be rejected or rectified is represented by the shaded areas again in Figure 6. If the proportion is more than negligible the designer can decide in advance what should be done when a particular joint proves too narrow or too wide and devise 'stand-by' joint designs for use on such occasions; or he can consider other options, such as changing the joint design to one with wider working limits of joint clearance, or changing the form of construction to one with a characteristically narrower distribution curve of inaccuracy.

In Figure 3 it was supposed that the normal distribution of accuracy in sizes was centred on the intended size (as shown again in Figure 7(a)). Sometimes it may be characteristic of the way a particular kind of item is made or built that the sizes produced are on average a little larger or smaller than intended, Figure 7(b); when this happens the effect of a particular chosen tolerance is markedly different. For example, in Figure 7(c) the achieved mean is coincident with the target and chosen tolerance limits carry an equal risk of rejection of both 'too small' and 'too large' items. But in Figure 7(d) the distribution is about a slightly larger size than the indended size; the total proportion likely to need correction or rejection has increased considerably compared with that in Figure 7(c), and, moreover, nearly all the unacceptable items are of one kind: in this case too large.

So, Figure 3 tells us that it is the *shape* of the distribution of inaccuracy that we need to know and Figure 7(d) tells us, equally importantly, that we need to know on which dimension the distribution is *centred.* Figure 7(d) also illustrates how important it is to choose the right target size. Taken together, the two illustrations show that, as a description of the accuracy of a particular kind of operation, 3000 ± 15 mm tells us very little and may even mislead us into an appreciable underestimate of the likely need for rejection and correction. Fortunately, a realistic way of describing the accuracy that is characteristic of a process is readily available. It is *mean* (the value on which the distribution is *centred*) and *standard deviation* (a value that describes the shape, or *spread,* of the distribution). A set of measurements with small deviations from the mean has a small spread and hence a small standard deviation, Figure 8(a). A set with larger deviations has a larger spread and a larger standard deviation, Figure 8(b). Figure 8(c) shows the proportion of items expected to deviate more than one, two or three standard deviations from the mean.

An accuracy description of this kind can be used to make predictions of the probability that the parts of buildings will fit together and produce satisfactory joints, and, on the basis of such predictions, a choice can be made of target sizes for construction and components that will give the best chance of straightforward building uninterrupted by problems of lack of fit. An explanation of these techniques is given in *Graphical aids for tolerances and fits,** a Building Research Establishment Handbook, for manufacturers, designers and builders, which removes the need for complex and repetitive calculations and hence minimises the time and effort spent at the design stage considering all the factors that affect fit.

* Graphical aids for tolerances and fits: HMSO, London, £15.50.

Availability of information

An extensive survey of the accuracy achieved in building construction has been carried out by the industry itself and has provided descriptions of the accuracies that are characteristic of dimensions in various forms of construction. The information will be contained in a BSI Code of Practice *Accuracy in Building.* The survey will provide real, practical, measured accuracy values that can be used in conjunction with the Graphical Aids to predict how well a given design will fit together in practice. But the Graphical Aids that enable this prediction to be made can also be used 'in

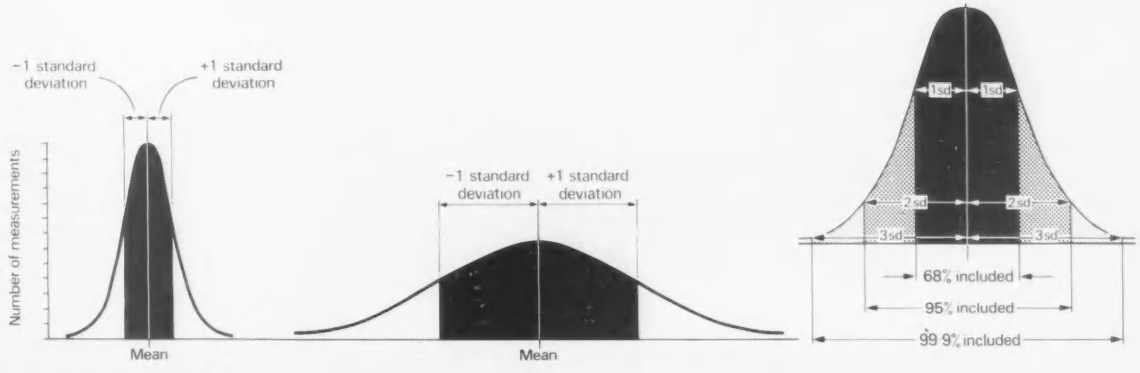


Fig 8 Standard deviation

reverse' so that when measured information about accuracy is not available the requirements for accuracy can nevertheless be identified and specified for any selected probability of satisfactory fit. However, it is not possible to specify this required accuracy in terms of 'mean and standard deviation' since these are essentially measured values and can therefore only be obtained after the event. In this case, a specification of required accuracy can only be in terms of limits, or tolerances, and we are obviously less well equipped than if we had measurements of the characteristic accuracy of the process concerned. This deficiency is to some extent compensated for, provided we check that the accuracy achieved is substantially within the required limits. All tolerances are useless unless adequate checks are made for compliance with them: merely to 'specify' is not enough.

Basis for choosing target sizes

Consider a provisional design in which a component will have to fit between two others, perhaps two structural components, that will be erected first, Figure 9. It would be impracticable to make the parts to the dimensions X mm and Y mm: there would be no space for joints even if the parts could be made with absolute precision to those dimensions.

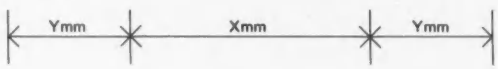


Fig 9 Provisional dimensional design

But X mm and Y mm are quite satisfactory for initial dimensional planning purposes: they represent the *order* of size of the parts. They therefore enable co-ordination of the dimensions of parts so that, to return to the introduction of this digest, the dimensions of kitchens and of kitchen furniture, for example, are of the right order of size to achieve a match between them.

But the target size, known also as the 'work size', of either the X component or the Y component, or both X and Y together, will need to be smaller than X mm and Y mm to provide space for the joints and an allowance for inaccuracies. Since those inaccuracies will make themselves apparent at the joints it will be necessary to compare their potential effect on joint clearances with the limits of joint clearance that are acceptable in the joint design. We can then make an assessment of how well the parts will fit, with satisfactory joints, in the way that is illustrated schematically in Figure 6. Ideally, we shall want to choose target sizes for the X and Y components such that the centre of the distribution in Figure 6 is at the centre of the required joint clearance range, and the shaded areas in Figure 6 representing 'misfits' are kept to a minimum, as in Figure 10.

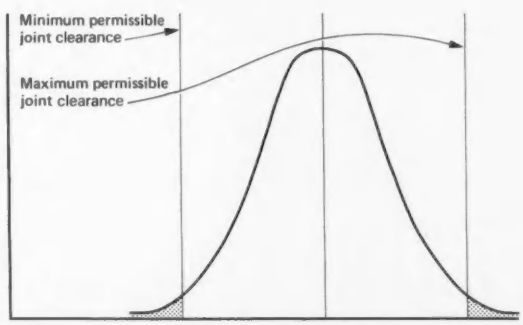


Fig 10 Minimum misfits

We cannot know in advance what particular inaccuracy any individual one of the parts in a particular assembly will have. But if we know, as a result of measuring such items in the past, the kind of accuracy that is characteristic of them, we can express this characteristic accuracy in terms of mean and standard deviation and thus provide a basis for adjusting our decision towards the ideal state represented by Figure 10. The Graphical Aids enable us to see what adjustments are necessary to which decisions, in order to optimise the likelihood of satisfactory fit. Returning once more to the introduction, we can choose target sizes that minimise the risk that the builder will have to cut a chase to accommodate the bath flange.

Designing for fit

Suppose we want to examine a real situation corresponding to the theoretical example in Figure 9. For example, 'X' is a pre-cast concrete panel which will have to be inserted between two 'Y's which are in-situ concrete columns; the co-ordinating sizes are shown in Figure 11.

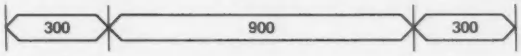


Fig 11 Co-ordinating sizes

Suppose the target size for the columns is fixed by structural considerations at 290 mm; we have selected a suitable joint and its limits of joint clearance are not less than 5 mm or more than 10 mm. What target size should we adopt for the concrete panel and how well will it fit?

Reference to the Graphical Aids, using appropriate values for inaccuracy in components and construction, would show at once that this design is impracticable because there will be potentially quite large inaccuracies to be accommodated by each of only two joints; joints, moreover, that we had wished to restrict to a clearance range of 5 mm minimum to 10 mm maximum. We could provide more space for the accommodation of inaccuracy by increasing the number of joints. Again, we would see that we would have to subdivide the concrete panel into 30 (with 5 to 10 mm joints between each) before a reasonable expectation of fit could be achieved; since the co-ordinating size of each panel would then be only 30 mm this is clearly impracticable. We could redesign the original two joints, choosing a joint design with a range, between working limits of clearance, that is larger than 5 to 10 mm. The Graphical Aids quickly show that we would need a joint design with a working range of 5 mm minimum to 25 maximum before the predicted risk of misfit (ie of exceeding the range) is down to 1 chance in 40.

Because the work size of the columns was fixed at 290 mm, the corresponding target size for the space between them will be 10 mm larger than the co-ordinating size of the space. Further reference to the Graphical Aids gives a target size, for the panel, of 880 mm. This is a size which is associated with a probability, in these circumstances, not worse than 1 in 40 of misfitting either the minimum or the maximum joint clearance.

The technique can, of course, be applied to many more construction situations than those represented by this one example. Component manufacturers can use it just as readily as building designers. And, whatever decisions are made by them, the builder can foresee their practical consequences: the likelihood and the nature (joints too large or too small) of potential misfits.

In principle, the technique can be applied to the selection of any dimensions where fit is involved. For example, even if components are to be 'built-in' as the work proceeds it may prove invaluable that they have a target size such that they could be inserted later: late delivery, insufficient storage space on site or other organisational problems may make it impossible to build them in as intended. The application of the technique to particular forms of construction is, in many cases, obvious. Sometimes, however, the user will have to give some prior thought aimed at interpreting a proposed construction into terms that the technique can handle.

When the technique was applied by BRE to a number of buildings that had recently been completed it was concluded that, if it had been available to the designers, better decisions about dimensions, accuracy and joints would have been made in every case. The resulting improvement in the fit of the various parts of the construction would have reduced the incidence and severity of assembly difficulties and would have improved the subsequent performance in use.

The Graphical Aids enable designers to predict the consequences of alternative dimensional decisions. Getting good fit depends very much on making the right decisions so as to ensure a satisfactory relationship between accuracy, joints, costs, the probability of successful implementation on site, and—most important—acceptable performance in use.

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